THE TUNGSTEN LAMP

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ARMOUR INSTITUTE OF TECHNOLOGY

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Tungsten lamp as a secondary
standard of light

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The Tungsten Lamp

As a Secondary Standard of Light

A THESIS

PRESENTED BY

HENRY J. BREMERS, Jr.

AND

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TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

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ELECTRICAL ENGINEERING

MAY 26th, 1910

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THE SERIES TUNGSTEN AS A SECONDARY STANDARD

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CONCLUSION

INTRODUCTION

Manufacture:

One of the most recent advances in electric lighting has been the introduction of the metallic filament incandescent lamps. By a peculiar coincidence the man who gave gas lighting such an advantage over electric lighting by the invention of the Welsbach burner overcame this advantage to a great extent by the invention of the metallic filament lamps. This man was Aver von Welsbach, who by his invention of the osmuim, tantalum and above all the tungsten lamp, has practically revolutionized electric lighting with incandescent lamps.

The following processes or some slight variations of them are the most prominent in the manufacture of these lamps:

Aver's Process:

Aver's process is essentially as follows: a paste of tungsten oxide is made and forced through an orifice in a diamond at a very high pressure, it is then heated by an electric current and passed into an electric furnace in an atmosphere of hydrogen and steam, where the oxide is reduced to the metallic tungsten which exists as small particles of tungsten sintered together. The wire as it comes from the furnace is either wound up on a roller or cut into predetermined lengths. The speed of the moving wire is about two millimeters per second. The leading-in wire is melted down to a

small globule at the end, which holds the filament securely, the resistance of this contact being negligable.

Just & Hanamann's Process:

The flashing process of Just & Hanamann consists in taking a carbon filament from .02 to .06 m.m. in diameter and heating it bright red by an electric current in an atmosphere of volatile tungsten compounds, generally the chlorides and oxychlorides, in the presence of hydrogen. The heat causes the hydrogen to reduce the tungsten compounds and the tungsten is deposited homogeneously on the carbon filament. Then the filaments are submitted to the action of an electric current in an atmosphere of hydrogen at 20 m.m. pressure, until they show the clearest white incandescence. This causes the carbon to be absorbed as carbide. Now the filaments are raised to a high temperature while surrounded by an atmosphere of hydrogen and steam. The carbon is oxidized leaving a filament, hollow in the center, of metallic tungsten. This filament is mounted in the leading-in wires by means of a paste consisting of finely divided tungsten mixed with coal tar or gum. These paste mounts are dried and made red-hot before the filament is heated in the bulb.

Manufacture with Aid of Organic Substances:

The Wolfram Lamp Co. has patented a metallic filament consisting of a mixture of metallic tungsten and small quantities of a more easily

fusible metal such as chromium, vanadium, tantalum or thorium. In order to produce such filaments an organic binding medium such as chloride of zinc, cellulose or acetic acid collodion is mixed with the finely divided tungsten containing about fifteen per cent of one of the above mentioned metals. The mixture is then formed into filaments and the filaments are decarbonized after denitration.

Another method described by E. Goosens Pope & Co. is as follows: a sodium-tungsten solution is mixed with no more than eight per cent of gallic acid and precipitated with acid. The precipitate containing a mixture of low tungsten oxides and small quantities of pyrogallol is washed first with water, then with equal parts of water and ninety-six per cent alcohol until all sodium salts have been removed. The paste thus obtained is pressed into filaments which must be dried slowly in order to give them sufficient solidity for succeeding processes. The dried filaments are heated in carbonic acid gas to about six hundred degrees centigrade, where we get a filament which consists of a metallic carbide, metallic oxide and metal. It has however, still a low melting point on account of its metallic impurities and it is therefore subjected to a further reduction in a hydrogen atmosphere, where the oxide is reduced to metal.

One method of decarbonizing filaments is to glow them in an atmosphere of acetic acid vapors.

Method of Lux:

In a method described by Johann Lux of Vienna he relies upon colloidal tungstic acid which, when combined with a little water, forms a tough sticky fluid which can be used as a binding material. Filaments are pressed from the mass and dried by a moderate heat and treated in an atmosphere of hydrogen.

Methods of Siemens Halske Co.:

The Siemens Halske Co. have devised a method which consists in tightly pressing powdered metallic tungsten or a mixture of difficultly fusible metal powders into a tube of other ductile metal, rolling and drawing it together with the latter and then removing the envelope either chemically, mechanically or by fusion. Thorium and Zirconium are used as envelopes. This method is found to be reliable and simple if the metal used as an envelope is not used as a powder but as a spongy mass.

Another of Siemens Halske Co.'s methods is to press powdered tungsten into a tube of copper, silver or nickel which has been inserted in a tube of steel. The ends are then closed by copper plugs and the tubes are rolled and drawn into filaments. The steel is then dissolved by dilute hydrochloric or sulphuric acid, and the filament is shaped. The inner tube is then removed by heating in a vacuum or a hydrogen atmosphere by an electric current.

In order to reduce the size of filaments the Siemens Halske Co. treats them with phosphorus vapors. The filaments are heated to a high temperature in the presence of phosphorus vapors of low pressure, if necessary in the presence of diluted gases such as hydrogen. By this method the thickness is diminished with great uniformity.

The latest methods of manufacturing filaments aim to replace fluids by metallic binding materials.

Life:

The life of a tungsten lamp will average between 800 and 1000 hours and the change in candle power during that time will be so small that it will scarcely be noticed. Only the pure tungsten however, has this long life, as impurities such as the tungsten salts seem to shorten the life of the lamp.

Breakage:

At first there was a large percentage of breakage due to the frailty of the filament but the General Eclectic Co. shipped over 100,000 lamps last year and the breakage was reduced to about 1-1/2% by the extreme care taken in packing and handling the lamps.

Advantages:

From the standpoint of current consumption, candle-power, total watts and watts per candle, they are less susceptible to a change in voltage than the carbon lamp, as the resistance in-

creases with the voltage, while in a carbon lamp it decreases with a rise in voltage.

In street lighting there is great economy in the series tungsten lamp. In fact there are two distinct advantages in the tungsten lamp; first, in the kilowatt hours saving per year, a tungsten lamp requiring only one third of the power of a carbon lamp; and secondly, in the extra capacity of the constant current transformers and station apparatus, the capacity of the station being about three times as many lamps as before.

The Series Tungsten:

The series lamp shows little variation in candle power during a life of about 1500 hours; there is practically no blackening, and the specific consumption of the lamp does not rise above 125%. The filaments of these lamps are particularly strong due to greater cross section and they are able to withstand any vibration caused by wind storms, men climbing poles,or from any other source. In fact, in a paper on Series Tungsten lighting by Henry Schroeder read before the 17th Annual Convention of the Northwestern Electrical Association, Milwaukee, Wis., Jan. 20-21,1909, Mr. Schroeder says: "An interesting occurrence happened last July in a town in New Jersey when lightning struck the series line and went through thirty-three (33) Tungsten lamps, curling the filaments without breaking the lamps. The film cutouts were punctured.

and when new films were installed the lamps lighted again. The lamps had burned 1200 hours before the storm came and are still burning to date, over 2000 hours. This same stroke of lightning jumped from the series line into a house, burning out a transformer, ripping off a door sill and passing into the ground through a steam radiator."

Characteristics:

The Chief characteristics of the tungsten lamp are the comparatively low consumption of energy and the extremely white quality of the light.

Specific Consumption:

The efficiency of a lamp during an average life of 800 hours will lie between 1-1/4 and 1-1/2 watts per candle.

Cost:

Although the initial cost of tungsten lamps is greater than that of carbon, they are cheaper in the long run, as they require only about one-half or one-third of the power consumed by a carbon lamp, and their life is longer than that of a carbon lamp.

The following gives an idea of the initial cost of the lamps. It is taken from a table in Central Stations for July, 1908 :

32 c.p.	40 watts	$1.50
48 c.p.	60 watts	1.75
80 c.p.	100 watts	2.00

OBJECT.

It is the object of the authors of this thesis to obtain data on the series tungsten lamp which will show the variation in candle-power with the time of "run" of the test.

The authors will also endeavor to show that, as a secondary standard of comparison, the tungsten filament lamp excels the carbon filament lamp, which at present is the accepted secondary standard of comparison. To do this, it will be necessary to obtain data which will show that the tungsten lamp maintains its candle-power constant, for a greater length of time, than the carbon-filament lamp.

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(Amer.Gas Light Journal - July 20-08)

The tungsten lamp - F.W.Wilcox.

(Elec.World - Sept. 5, '08)

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(Elec.World - Jan. 4 - 08)

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(Elec. Review and Western Electrician,
Jan. 1, '10 and Jan. 8, '10)

APPARATUS.

Galvanometer Circuit:

2 - 300 ohms telegraph relays.

1 - model 30 - #376 galvanometer relay.
(Weston Elec. Co.)

7 - #6 Columbia dry cells.

Bridge Circuit:

2 - 32 c.p. - carbon lamps

1 - 16 c.p. - " "

4 - 25 watt - 110 volt - tungsten lamps

1 - 25 " - 110 " tantulum "

1 -433 ohm - 110 " 1 ampere rheostat
(National Rheostat Co.)

1 - (0-150) - d.c. voltmeter.
(Western Elec. Co.)

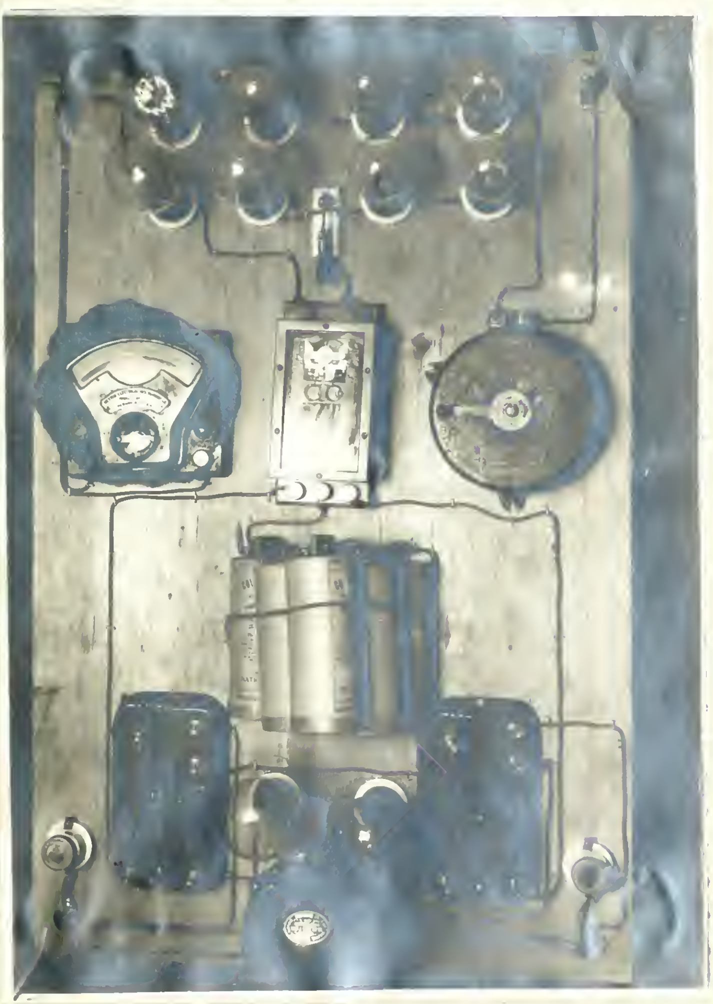
Motor Circuit:

1 - 1/10 horse-power - d.c. motor

(Fort Wayne Elec. Co.)

2 - 32 c.p. - carbon lamps.

PHOTOGRAPH OF GALVANOMETER, BRIDGE AND MOTOR CIRCUITS.



Lamp Circuit:

9 - 30 watt - 12 volt - 2-1/2 ampere tungsten lamps. (General Elec. Co.)

1 - 4 ohm - slide-wire resistance.

1 - 3 ampere d.c. ammeter.
(Siemens and Halske)

1 - 25 ohm - 3.5 ampere rheostat
(General Elec. Co.)

1 - Recording electric clock.
(Walker Electric Co.

Photometric Circuit:

1 - Lummer - Brodhun photometer and accessories.

2 - 25 ohm - 3.5 ampere rheostats.
(General Elec. Co.)

2 - 4 inch. plate - carbon rheostats.

1 - 3 ampere d.c. ammeter.
(Siemens and Halske)

1 - (0-15) d.c. voltmeter.
(Weston Elec. Co.)

1 - (0-15) d.c. "standard" voltmeter.
(Weston Elec. Co.

1 - 16 c.p. standard carbon lamp
(New York Elect.Testing Laboratories)

PROCEDURE.

Throughout the test it was necessary to maintain a constant current through the lamps and therefore a constant potential across the lamps, in order to obtain data, which would be consistent, in that each lamp would be worked under the same conditions. In order to maintain a constant potential across the lamps it was necessary to have three circuits, i.e.: a galvanometer circuit, a motor circuit, and a Wheatstone bridge circuit.

To determine the candle-powers of the lamps it was necessary after each run to place the lamp under test, in the same position in the socket. This end was accomplished by placing the plane of the filament perpendicular to the scale. In this manner the true variation in candle-power was obtained each time.

The average letngth of each run was about fifty hours and in all the total length of the various runs was four hundred and fifty hours.

DESCRIPTION OF APPARATUS.

The Wheatstone bridge circuit:

The Wheatstone bridge circuit consisted of four twenty-five watt tungsten filament lamps in one arm, one sixteen-candle-power carbon filament lamp in the second arm, two thirty-two candle-power carbon filament lamps

in the third arm, and one twenty-five watt tantulum filament lamp in the fourth arm.

A relay galvanometer was so connected between two of the arms, so that with a rise in voltage its needle was deflected in one direction, while with a decrease in voltage, its needle was deflected in an opposite direction.

It is a well known fact that with a rise in voltage the resistance of the carbon filament lamp decreases, while the resistance of the tungsten and tantulum filament lamps increases. Advantage was taken of this fact by making the connections as explained under the various circuits.

The Galvanometer Circuit:

The galvanometer circuit consisted of a relay galvanometer, two ordinary telegraph relays and seven dry cells. When the needle of the galvanometer moved in one direction it would close one of the relays, and when it had moved in the opposite direction it would close the other relay.

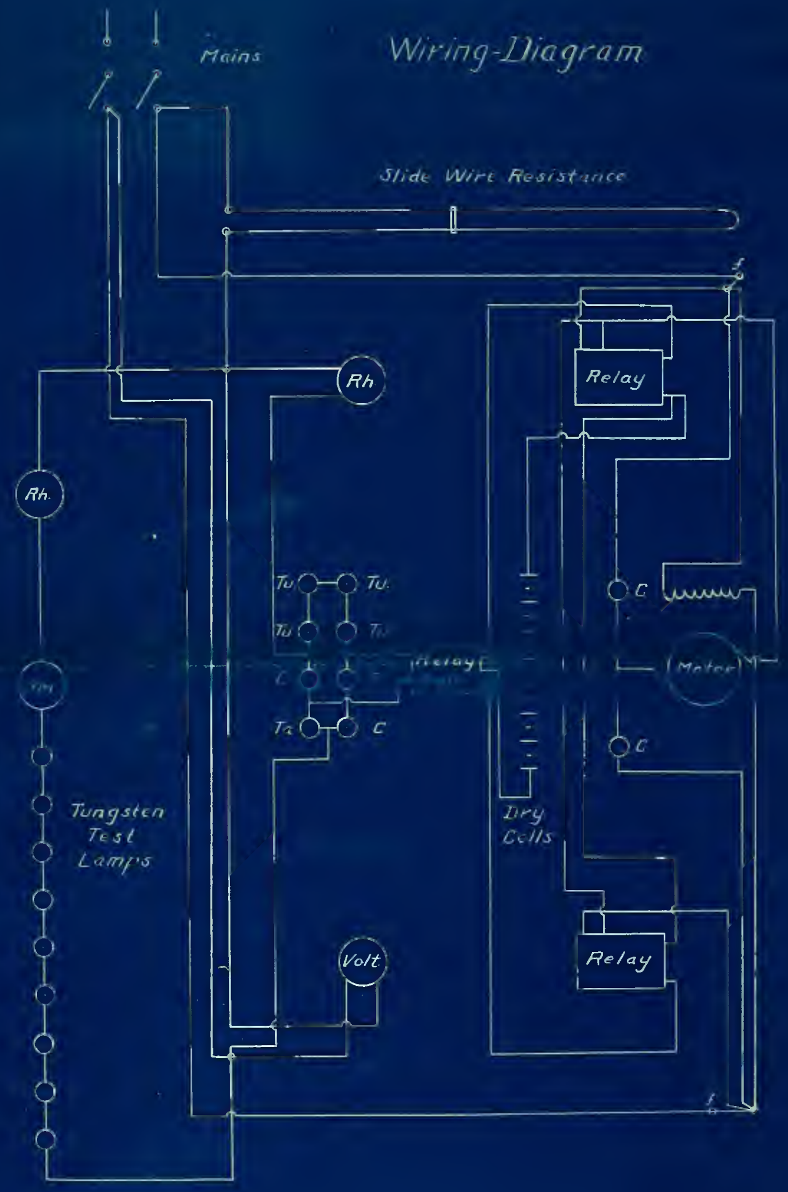
The Motor Circuit:

A one-tenth horse-power motor was so connected as to rotate in one direction when one of the relays was closed, and to rotate in an opposite direction when the other relay was closed. The motor was belted to a pulley, which in turn was belted to a sliding contact. This sliding

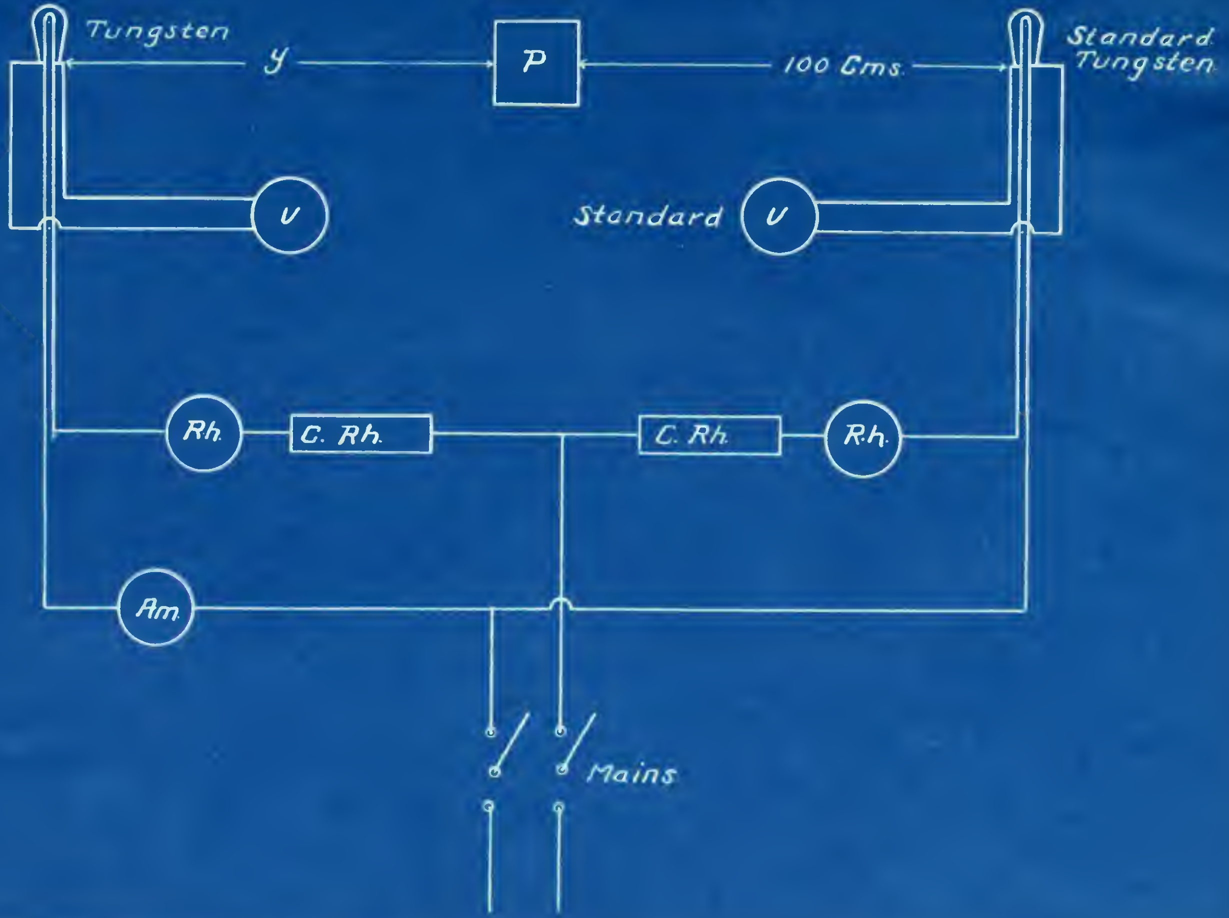
contact was so arranged as to move along a loop of wire having a resistance of twenty-five ohms. This resistance was connected in series with the main circuit.

When the voltage of the system increased, resistance would thus be cut into the circuit until the normal voltage was reached, and at this point the needle would be at a neutral position, while the motor would be at rest. If the voltage decreased resistance would be cut out of the main-circuit and the normal voltage would again be reached and again the motor would be at rest. This condition would continue as long as the apparatus was connected for operation. Thus automatically the voltage was controlled.

Wiring-Diagram


Mains
Slide Wire Resistance
f
Relay
Rh
Rh.
Tu
Tu.
Tu
Tu
C
Ta
C
Relay
C
C
Motor
M
Dry Cells
Volt
Tungsten Test Lamps
Relay
f

Photometric Diagram


Tungsten
y
P
100 Cms.
Standard Tungsten
V
Standard
V
Rh.
C. Rh.
C. Rh.
R.h.
Am.
Mains

DATA

Lamp A

X	E	I	C.P.	Sp.Con.
98.5	8.35	2.04	5.99	2.844
92.7				
97.9				
92.5				
99.0				
93.0				
95.6				
95.3	8.5	2.00	6.48	2.623
95.0				
95.0				
95.4				
95.1				
95.2				
95.1				
94.7	8.3	2.00	6.40	2.595
94.5				
94.3				
94.8				
94.3				
94.7				
94.5				

Lamp A

X	E	I	C.P.	Sp.Con.
93.9	8.15	2.00	6.29	2.595
93.8				
94.0				
93.7				
93.5				
93.6				
93.7				
95.3	8.20	2.00	6.65	2.465
94.9				
95.3				
95.4				
95.0				
94.9				
96.4				
93.9	8.175	2.00	6.30	2.597
93.8				
93.9				
93.8				
93.8				
93.8				
93.8				

Lamp A

X	E	I	C.P.	Sp.Con.
92.8	8.1	2.00	6.2	2.615
93.0				
92.7				
93.4				
93.2				
93.2				
93.05				
92.1	8.125	2.00	6.09	2.666
92.4				
92.2				
92.2				
92.4				
92.5				
92.26				
91.3	8.125	2.00	5.98	2.72
91.5				
91.5				
91.5				
91.2				
91.5				
91.4				

Lamp A

X	E	I	C.P.	Sp.Con.
93.5	8.18	2.00	6.23	2.67
93.5				
93.6				
93.5				
93.6				
93.6				
93.55				
93.1	8.225	2.00	6.25	2.63
93.8				
93.6				
93.1				
93.8				
93.5				
93.49				
95.5	8.15	2.00	6.52	2.50
95.2				
95.5				
95.7				
95.3				
95.5				
95.45				

Lamp B

X	E	I	C.P.	Sp.Con.
97.6	8.30	2.00	6.00	2.764
92.5				
98.6				
93.6				
99.2				
93.4				
$\overline{95.8}$				
94.6	8.25	2.00	6.41	2.574
94.7				
94.9				
94.7				
94.3				
94.4				
$\overline{94.6}$				
91.1	8.15	2.00	5.95	2.84
91.0				
91.5				
91.1				
91.4				
90.9				
$\overline{91.16}$				

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Lamp B

X	E	I	C.P.	Sp.Con.
93.3	8.15	2.00	6.21	2.625
93.2				
93.1				
92.9				
93.3				
93.0				
93.1				
95.2	8.25	2.00	6.50	2.54
95.3				
95.1				
95.4				
95.5				
95.3				
95.3				
97.1	8.23	2.00	6.69	2.46
96.3				
96.5				
96.7				
96.6				
96.5				
96.6				

Lamp B

X	E	I	C.P.	Sp.Con.
93.	8.175	2.00	6.21	2.63
93.2				
93.0				
93.2				
93.3				
92.9				
93.1				
95.0	8.275	2.00	6.49	2.55
95.1				
95.3				
95.0				
95.5				
94.9				
95.13				
94.9	8.2	2.00	6.45	2.54
95.1				
94.8				
94.8				
94.9				
94.8				
94.88				

Lamp B

X	E	I	C.P.	Sp.Con.
95.4	8.18	2.00	6.56	2.499
95.9				
95.7				
95.6				
95.6				
95.9				
95.68				
95.5	8.25	2.00	6.58	2.51
96.0				
96.0				
96.1				
95.7				
95.5				
95.8				
95.4	8.175	2.00	6.45	2.54
95.1				
95.6				
94.9				
94.8				
94.7				
95.01				

Lamp C

94.7	8.30	1.98	6.39	2.57
101.1				
95.7				
102.0				
96.2				
102.5				
98.7				
97.	8.50	2.00	6.80	2.50
97.1				
97.7				
97.7				
97.8				
97.3				
97.4				
95.3	8.40	2.00	6.50	2.585
95.7				
95.3				
95.2				
95.8				
95.2				
95.4				

Lamp C

X	E	I	C.P.	Sp.Con.
93.7	8.30	2.00	6.31	2.63
93.8				
94.1				
93.8				
93.9				
93.8				
93.85				
95.1	8.30	2.00	6.46	2.57
94.7				
95.2				
95.2				
94.9				
95.1				
95.				
98.1	8.34	2.00	6.92	2.41
98.8				
98.3				
98.3				
98.3				
98.6				
98.3				

Lamp C

X	E	I	C.P.	Sp.Con.
93.8	8.275	2.00	6.35	2.61
94.1				
93.9				
94.4				
94.1				
94.1				
94.06				
94.3	8.34	2.00	6.50	2.564
94.7				
94.7				
94.9				
94.9				
94.4				
95.3				
95.7	8.30	2.00	6.52	2.545
95.3				
95.3				
95.5				
95.6				
95.6				
95.5				

Lamp C

X	E	I	C.P.	Sp.Con.
95.9	8.34	2.00	6.55	2.545
95.6				
95.3				
95.5				
95.4				
95.9				
95.6				
95.9	8.30	2.00	6.53	2.54
95.3				
95.2				
95.6				
95.2				
95.6				
95.46				
94.3	8.25	2.00	6.28	2.63
93.7				
93.8				
93.8				
93.8				
93.7				
93.85				

Lamp E

X	E	I	C.P.	Sp.Con.
96.2	8.30	2.01	6.28	2.655
102.1				
96.8				
102.0				
97.1				
93.2				
97.9				
95.8	8.30	2.00	6.54	2.54
95.6				
95.2				
95.4				
95.6				
95.5				
95.5				
93.3	8.20	2.00	6.21	2.64
93.4				
93.2				
93.3				
93.1				
93.1				
93.2				

Lamp E

X	E	I	C.P.	Sp.Con.
93.3	8.14	2.00	6.21	2.62
93.2				
93.3				
93.1				
93.0				
93.0				
93.15				
97.6	8.20	2.00	6.81	2.405
97.6				
97.3				
97.5				
97.4				
97.7				
97.5				
95.4	8.15	2.00	6.51	2.504
95.7				
95.4				
95.3				
95.8				
95.2				
95.46				

Lamp E

X	E	I	C.P.	Sp.Con.
93.8	8.10	2.00	6.30	2.57
93.9				
94.1				
94.0				
93.8				
93.5				
93.85				
95.8	8.20	2.00	6.52	2.514
95.2				
95.5				
95.5				
95.2				
95.2				
95.4				
96.3	8.22	2.00	6.62	2.485
96.0				
96.2				
95.9				
96.1				
96.2				
96.1				

Lamp E

X	E	I	C.P.	Sp.Con.
94.3	8.16	2.00	6.35	2.574
94.3				
94.2				
94.1				
94.1				
94.3				
94.2				
96.2	8.30	2.00	6.625	2.505
96.5				
96.1				
96.1				
96.5				
96.0				
96.2				
95.3	8.20	2.00	6.50	2.52
95.6				
95.3				
95.3				
95.4				
95.3				
95.37				

Lamp F

X	E	I	C.P.	Sp.Con.
96.2	8.30	2.00	5.81	2.856
91.4				
97.5				
91.6				
96.8				
91.9				
94.2				
97.8	8.40	2.00	6.85	2.454
97.9				
97.7				
97.6				
97.9				
97.6				
97.75				
93.6	8.30	2.00	6.26	2.65
93.8				
93.2				
93.2				
93.6				
93.7				
93.5				

Lamp F

X	E	I	C.P.	Sp.Con.
95.6	8.28	2.00	6.51	2.54
95.7				
95.4				
95.5				
95.1				
94.9				
95.35				
93.2	8.15	2.00	6.22	2.62
93.1				
93.2				
93.1				
93.1				
93.6				
93.2				
94.6	8.22	2.00	6.39	2.58
94.8				
94.2				
94.2				
94.1				
94.5				
94.4				

Lamp F

X	E	I	O.P.	Sp.Con.
92.2	8.225	2.00	6.08	2.705
92.4				
92.0				
92.0				
91.9				
92.1				
92.1				
90.8	8.18	2.00	5.89	2.73
90.4				
90.6				
90.6				
90.7				
90.8				
90.65				
91.5	8.125	2.00	6.01	2.705
91.5				
91.7				
91.6				
91.6				
91.8				
91.6				

Lamp F

X	E	I	C.P.	Sp.Con.
92.2	8.15	2.00	6.08	2.68
92.3				
92.3				
91.9				
91.9				
91.9				
92.08				
93.3	8.22	2.00	6.22	2.64
93.5				
93.4				
93.5				
92.8				
92.8				
93.2				
92.6	8.20	2.00	6.10	2.69
92.3				
92.5				
92.0				
92.4				
92.3				
92.35				

Lamp G

X	E	I	C.P.	Sp.Con.
96.3	8.30	1.99	6.40	2.58
101.8				
95.9				
101.6				
95.3				
102.5				
98.9				
97.1	8.40	2.00	6.72	2.50
97.0				
96.7				
97.0				
97.0				
96.8				
96.9				
94.6	8.22	2.00	6.35	2.59
94.2				
94.2				
94.6				
93.9				
93.9				
94.2				

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				[illegible]

Lamp G

X	E	I	C.P.	Sp.Con.
95.3	8.34	2.00	6.45	2.585
94.9				
94.8				
95.0				
95.1				
94.8				
94.98				
96.8	8.32	2.00	6.64	2.505
96.0				
96.3				
96.0				
96.5				
96.5				
96.3				
96.1	8.32	2.00	6.65	2.50
96.6				
96.4				
96.3				
96.5				
96.2				
96.35				

Lamp G

X	E	I	C.P.	Sp.Con.
92.8	8.20	2.00	6.21	2.64
93.2				
93.2				
92.9				
93.1				
93.3				
93.08				
93.2	8.25	2.00	6.213	2.66
92.8				
93.2				
93.2				
93.1				
93.5				
93.16				
95.1	8.275	2.00	6.45	2.565
94.8				
95.0				
95.1				
94.8				
94.6				
94.9				

Lamp G

X	E	I	C.P.	Sp.Con.
92.8	8.225	2.00	6.14	2.698
92.6				
92.8				
92.4				
92.8				
92.4				
92.6				
95.7	8.32	2.00	6.56	2.50
95.3				
95.5				
96.1				
95.5				
95.9				
95.66				
95.2	8.30	2.00	6.46	2.57
95.2				
95.0				
95.0				
95.1				
95.0				
95.08				

Lamp H

X	E	I	C.P.	Sp.Con
94.9	8.30	1.98	6.20	2.654
100.1				
94.6				
99.5				
94.6				
100.1				
97.3				
97.8	8.425	2.00	6.82	2.47
97.9				
97.4				
97.5				
97.3				
97.4				
97.55				
95.3	8.42	2.00	6.49	2.595
94.9				
94.6				
95.4				
95.4				
95.4				
95.16				

Lamp H

X	E	I	C.P.	Sp.Con.
94.3	8.30	2.00	6.37	2.605
94.3				
94.0				
94.5				
94.6				
94.5				
94.35				
98.9	8.35	2.00	6.98	2.39
98.6				
98.7				
98.6				
98.9				
98.7				
98.73				
98.2	8.32	2.00	6.91	2.41
98.1				
98.3				
98.6				
98.1				
98.3				
98.26				

Lamp H

X	E	I	C.P.	Sp.Con.
96.2	8.30	2.00	6.65	2.5
96.6				
96.4				
96.6				
96.1				
96.4				
96.38				
97.8	8.35	2.00	6.86	2.435
98.0				
97.8				
97.6				
98.2				
98.1				
97.9				
97.4	8.35	2.00	6.79	2.46
97.4				
97.5				
97.5				
97.6				
97.5				
97.48				

Lamp H

X	E	I	C.P.	Sp.Con.
98.7	8.42	2.00	6.95	2.425
98.4				
98.3				
98.2				
98.8				
98.8				
98.53				
97.6	8.375	2.00	6.79	2.47
97.2				
97.4				
97.1				
97.2				
97.6				
97.35				
96.3	8.35	2.00	6.64	2.52
96.6				
96.3				
96.3				
96.7				
96.4				
96.43				

Lamp I

X	E	I	C.P.	Sp.Con.
105.7	8.30	2.01	7.00	2.38
100.7				
107.1				
100.5				
106.8				
100.2				
103.5				
95.9	8.30	2.00	6.56	2.53
96.0				
95.7				
95.8				
95.4				
95.9				
95.75				
92.7	8.25	2.00	6.15	2.684
92.4				
92.2				
92.9				
92.7				
92.8				
92.6				

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				[illegible]

Lamp I

X	E	I	C.P.	Sp.Con.
91.9	8.12	2.00	6.05	2.685
91.7				
91.6				
92.2				
92.3				
91.8				
91.9				
94.	8.175	2.00	6.35	2.575
94.2				
94.3				
94.1				
94.2				
94.1				
94.15				
95.2	8.16	2.00	6.82	2.395
95.2				
95.6				
95.0				
95.6				
95.0				
95.26				

Lamp I

X	E	I	C.P.	Sp.Con.
94.6	8.175	2.00	6.43	2.54
94.7				
94.8				
94.6				
94.9				
95.0				
94.76				
97.2	8.225	2.00	6.71	2.45
96.6				
96.7				
97.1				
96.9				
96.7				
96.86				
95.0	8.20	2.00	6.44	2.545
94.9				
94.7				
94.9				
94.5				
95.3				
94.9				

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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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				[illegible]
				[illegible]
				[illegible]
				[illegible]
				[illegible]
				[illegible]

Lamp I

X	E	I	C.P.	Sp.Con.
93.3	8.15	2.00	6.28	2.6
94.0				
93.8				
93.6				
93.5				
93.5				
93.6				
94.7	8.20	2.00	6.35	2.58
94.0				
94.0				
94.0				
94.4				
94.2				
94.2				
95.5	8.125	2.00	6.50	2.50
95.5				
95.0				
95.2				
95.9				
95.0				
95.35				

Lamp J

120.0	8.30	2.50	9.09	2.285
114.5				
122.3				
114.0				
120.8				
115.4				
117.8				
51.9	5.70	2.00	1.923	5.93
51.8				
51.8				
51.7				
51.5				
52.3				
51.8				
50.0	5.70	2.00	1.813	6.29
50.5				
50.3				
50.7				
50.9				
49.8				
50.36				

Lamp J

X	E	I	C.P.	Sp.Con.
51.4	5.70	2.00	1.926	5.92
51.9				
52.2				
52.3				
51.6				
51.7				
51.85				
49.2	5.69	2.00	1.74	6.55
49.1				
49.6				
49.3				
49.4				
49.1				
49.28				
50.3	5.60	2.00	1.827	6.14
50.6				
50.7				
51.0				
50.1				
50.3				
50.5				

Lamp J

X	E	I	C.P.	Sp.Con.
50.	5.57	2.00	1.73	6.8
49.9				
49.0				
48.4				
48.4				
49.3				
49.16				
47.7	5.5	2.00	1.64	6.71
47.9				
47.6				
47.8				
47.8				
48.3				
47.85				
48.5	5.55	2.00	1.602	6.92
47.3				
47.5				
46.4				
46.7				
47.3				
47.3				

Lamp J

X	E	I	C.P.	Sp.Con.
47.4	5.57	2.00	1.612	6.91
47.4				
47.3				
47.7				
47.5				
47.4				
47.45				
47.3	5.65	2.00	1.617	6.99
47.2				
47.6				
47.9				
47.3				
47.8				
47.5				
47.5	5.50	2.00	1.59	6.93
47.4				
47.0				
47.1				
47.4				
47.8				
47.37				

SUMMARY OF DATA.

	Lamp A			Lamp B	
C.P.	Sp.Con.	Hours	C.P.	Sp.Con.	Hours
5.99	2.844	0	6.00	2.764	0
6.48	2.623	53	6.41	2.574	53
6.40	2.595	95.5	5.95	2.84	95.5
6.29	2.595	132.5	6.21	2.625	132.5
6.65	2.465	171.0	6.50	2.54	171.
6.30	2.597	194	6.69	2.46	194
6.20	2.615	236	6.21	2.63	236
6.09	2.666	286	6.49	2.55	286
5.98	2.72	327	6.45	2.54	327
6.13	2.67	353	6.56	2.499	353
6.25	2.63	397	6.58	2.51	397
6.52	2.50	449	6.45	2.54	449

	Lamp C			Lamp E	
C.P.	Sp.Con.	Hours	C.P.	Sp.Con.	Hours
6.39	2.57	0	6.28	2.655	0
6.80	2.50	53	6.54	2.54	53
6.50	2.585	95.5	6.21	2.64	95.5
6.31	2.63	132.5	6.21	2.62	132.5
6.46	2.57	171	6.81	2.405	171
6.92	2.41	194	6.51	2.504	194
6.35	2.61	236	6.30	2.57	236
6.50	2.564	286	6.52	2.514	286
6.52	2.545	327	6.62	2.485	327
6.55	2.545	353	6.35	2.574	353
6.53	2.54	397	6.625	2.505	397
6.28	2.63	449	6.50	2.52	449

Lamp F

C.P.	Sp.Con.	Hours
5.81	2.856	0
6.85	2.454	53
6.26	2.65	95.5
6.51	2.54	112.5
6.22	2.62	171
6.39	2.58	194
6.08	2.705	236
5.89	2.73	286
6.01	2.705	327
6.08	2.68	353
6.22	2.64	397
6.10	2.69	449

Lamp G

C.P.	Sp.Con.	Hours
6.4	2.58	0
6.72	2.50	53
6.35	2.59	95.5
6.45	2.585	132.5
6.65	2.505	171.0
6.65	2.50	194
6.21	2.64	236
6.213	2.66	286
6.45	2.565	327
6.14	2.698	353
6.56	2.50	397
6.46	2.57	449

Lamp H

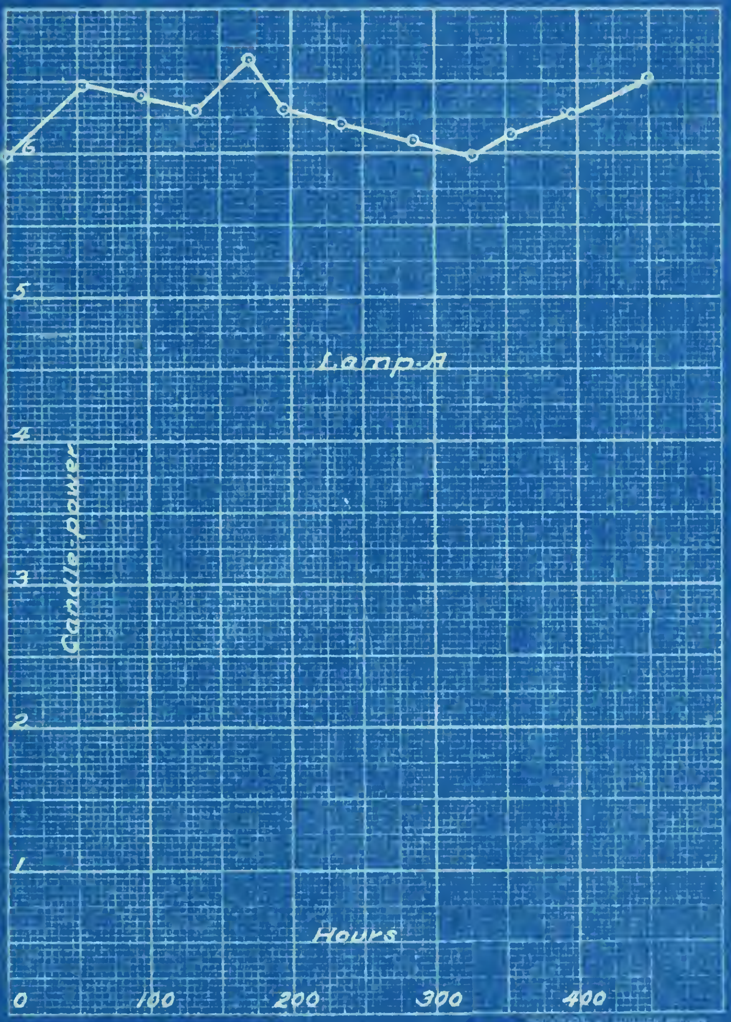
C.P.	Sp.Con.	Hours
6.20	2.654	0
6.82	2.47	53
6.49	2.595	95.5
6.37	2.605	132.5
6.98	2.39	171
6.91	2.41	194
6.65	2.50	236
6.86	2.435	286
6.79	2.46	327
6.95	2.425	353
6.79	2.47	397
6.64	2.52	449

Lamp I

C.P.	Sp.Con.	Hours
7.00	2.38	0
6.56	2.53	53
6.15	2.684	95.5
6.05	2.685	132.5
6.35	2.575	171.
6.82	2.395	194
6.43	2.54	236
6.71	2.45	286
6.44	2.545	327
6.28	2.60	353
6.35	2.58	397
6.50	2.50	449

Lamp J

C.P.	Sp.Con.	Hours
9.09	2.285	0
1.923	5.93	53
1.813	6.29	95.5
1.926	5.92	132.5
1.74	6.55	171
1.827	6.14	194
1.73	6.8	236
1.64	6.71	286
1.602	6.92	327
1.612	6.91	353
1.617	6.99	397
1.59	6.93	449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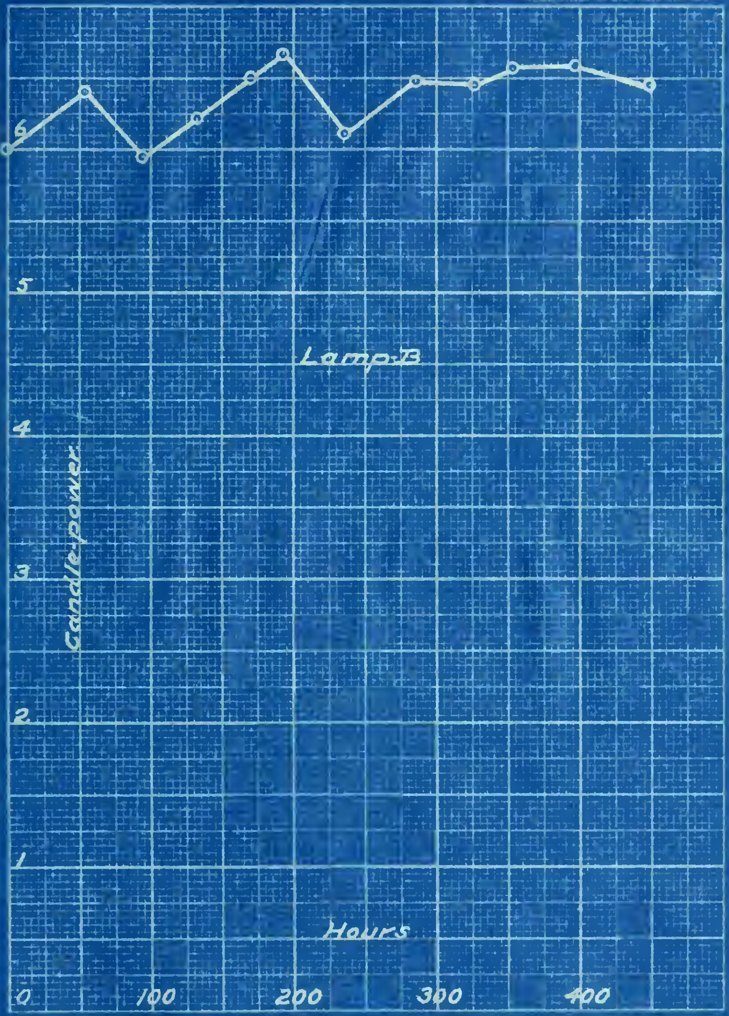
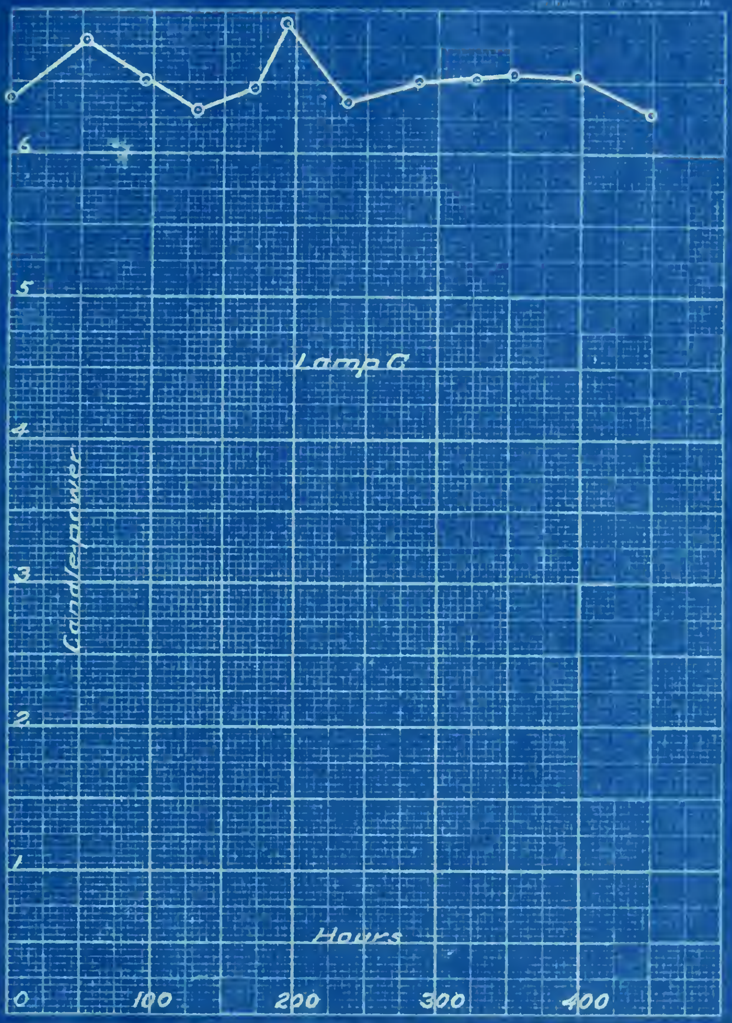
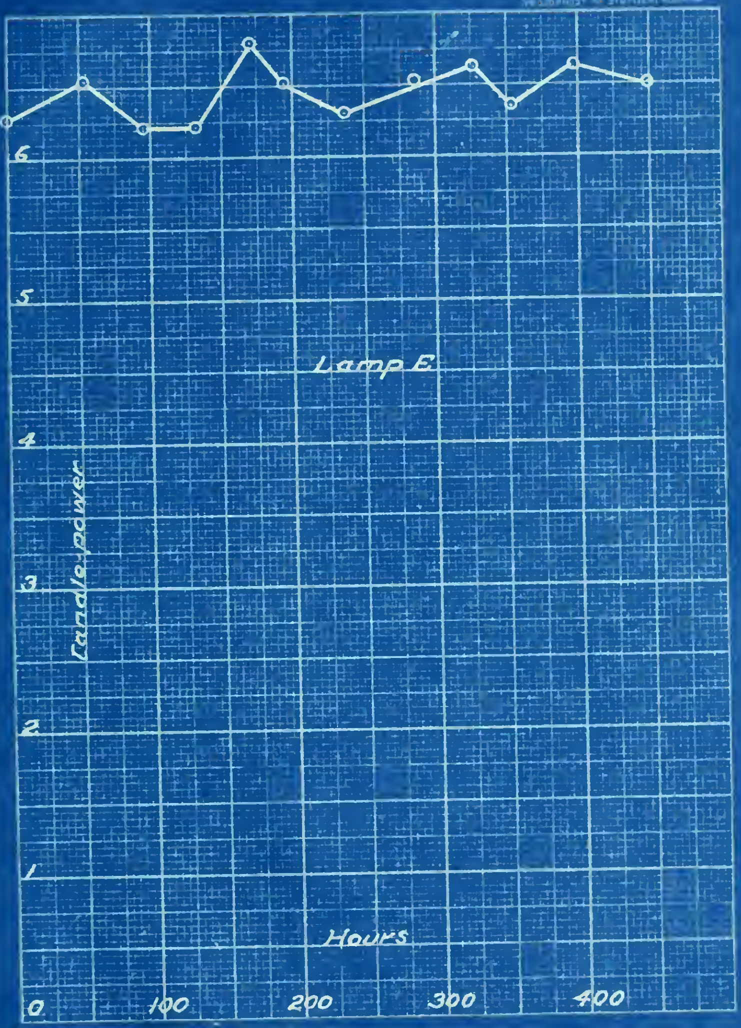
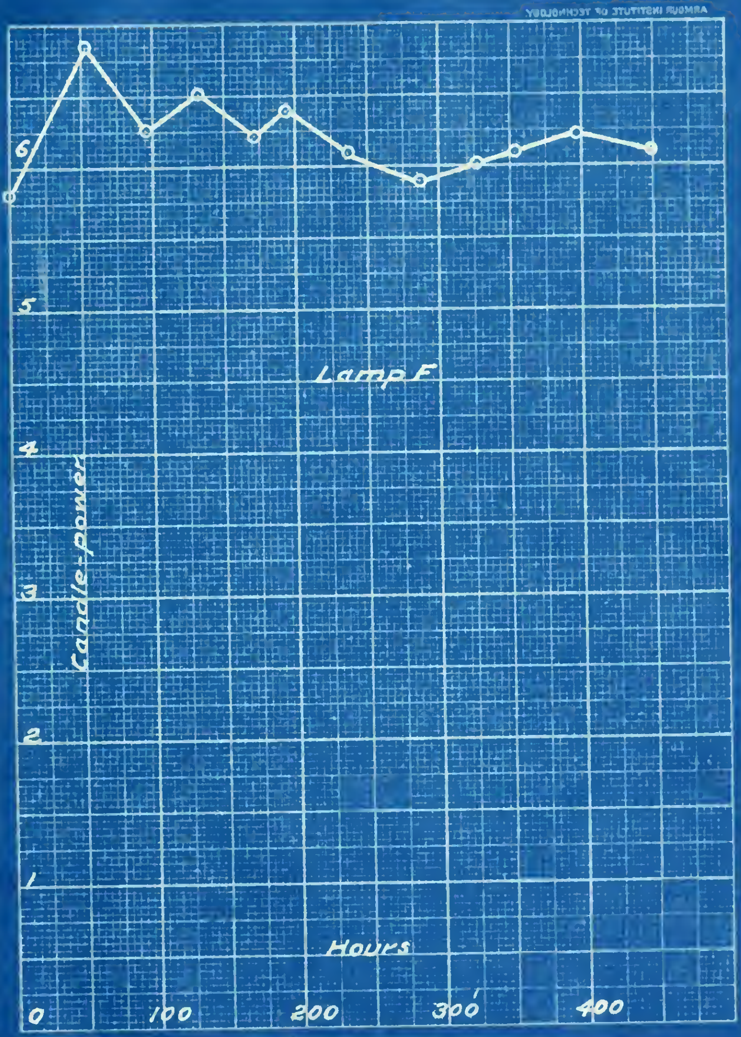
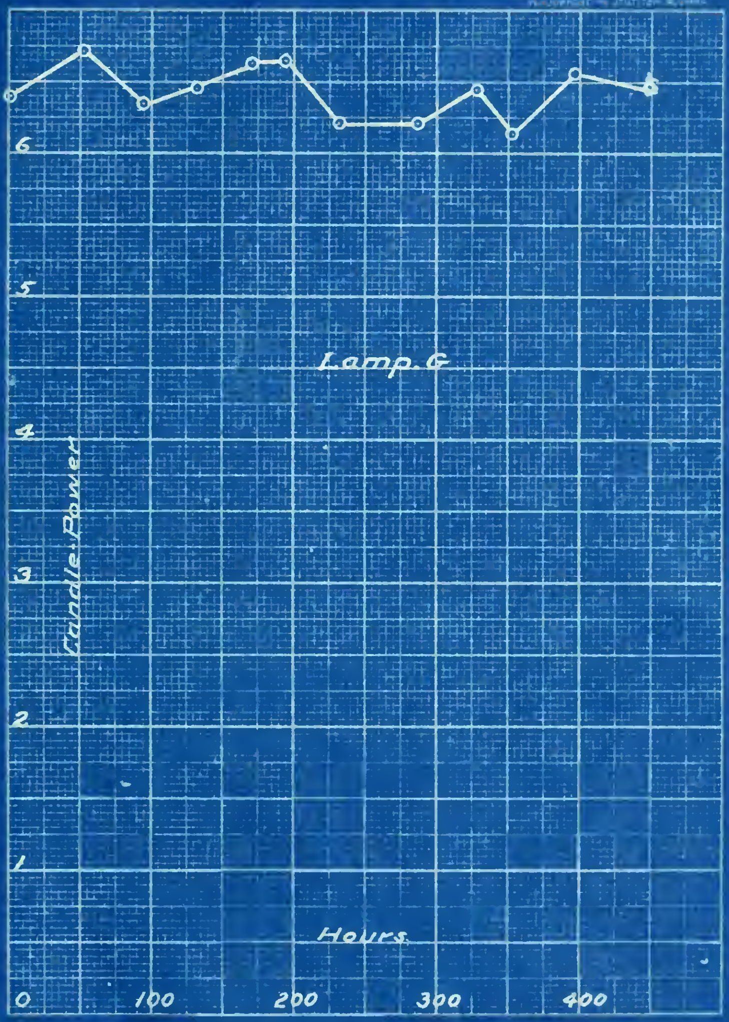
5
4
3
2
1
Candle-power
Lamp A
Hours
0
100
200
300
400

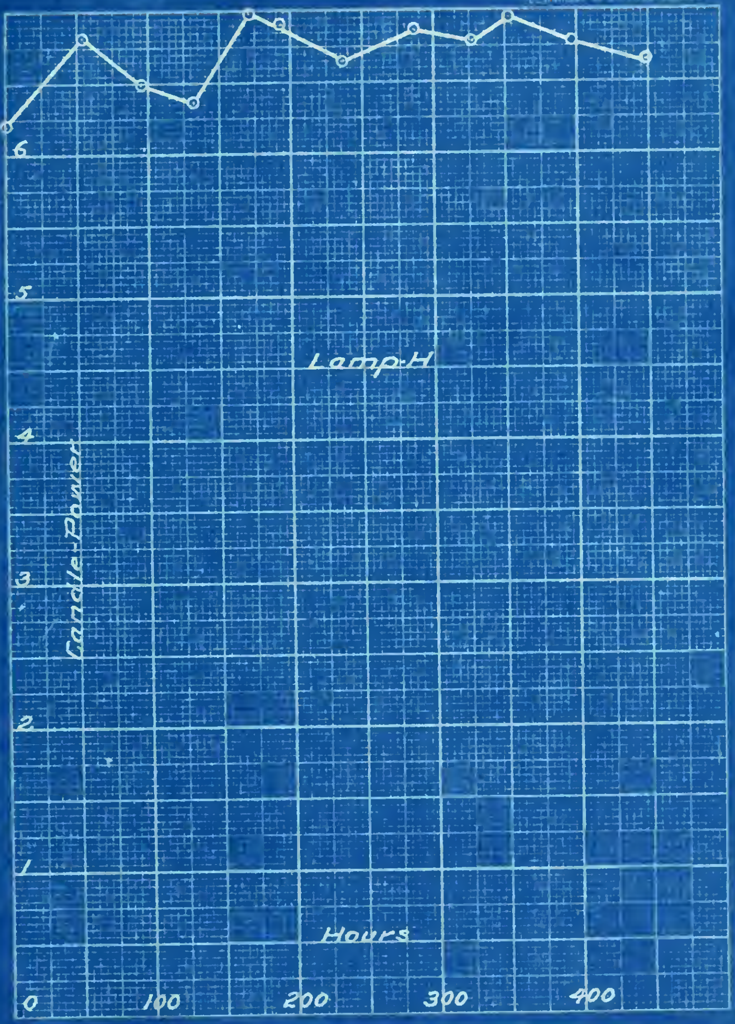

Lamp B
Candle-power
Hours
6
5
4
3
2
1
0
100
200
300
400


Lamp G
Candle-power
Hours
6
5
4
3
2
1
0
100
200
300
400

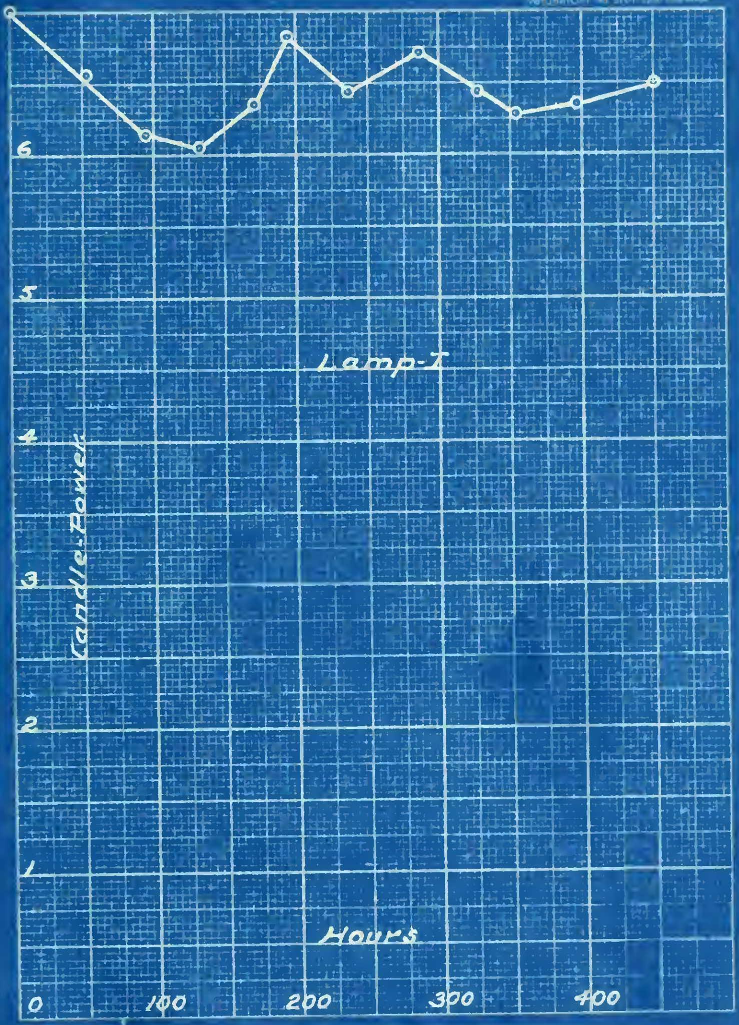

Lamp E
Candle power
6
5
4
3
2
1
0
100
200
300
400
Hours

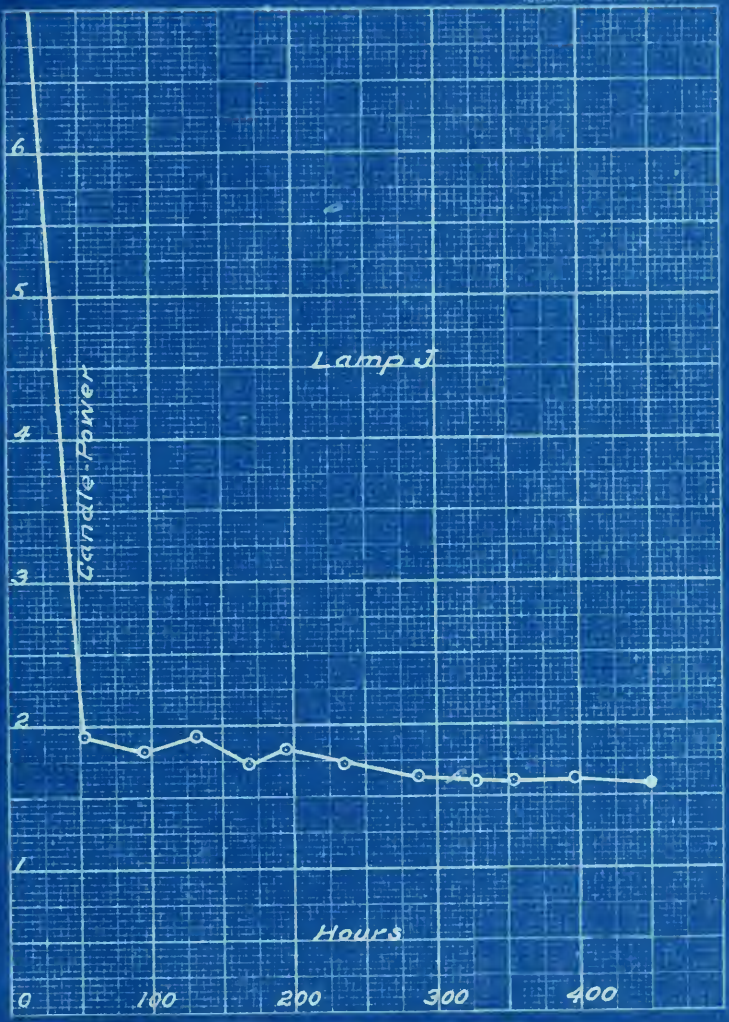

6
5
4
3
2
1
Candle-power
Lamp F
Hours
0
100
200
300
400

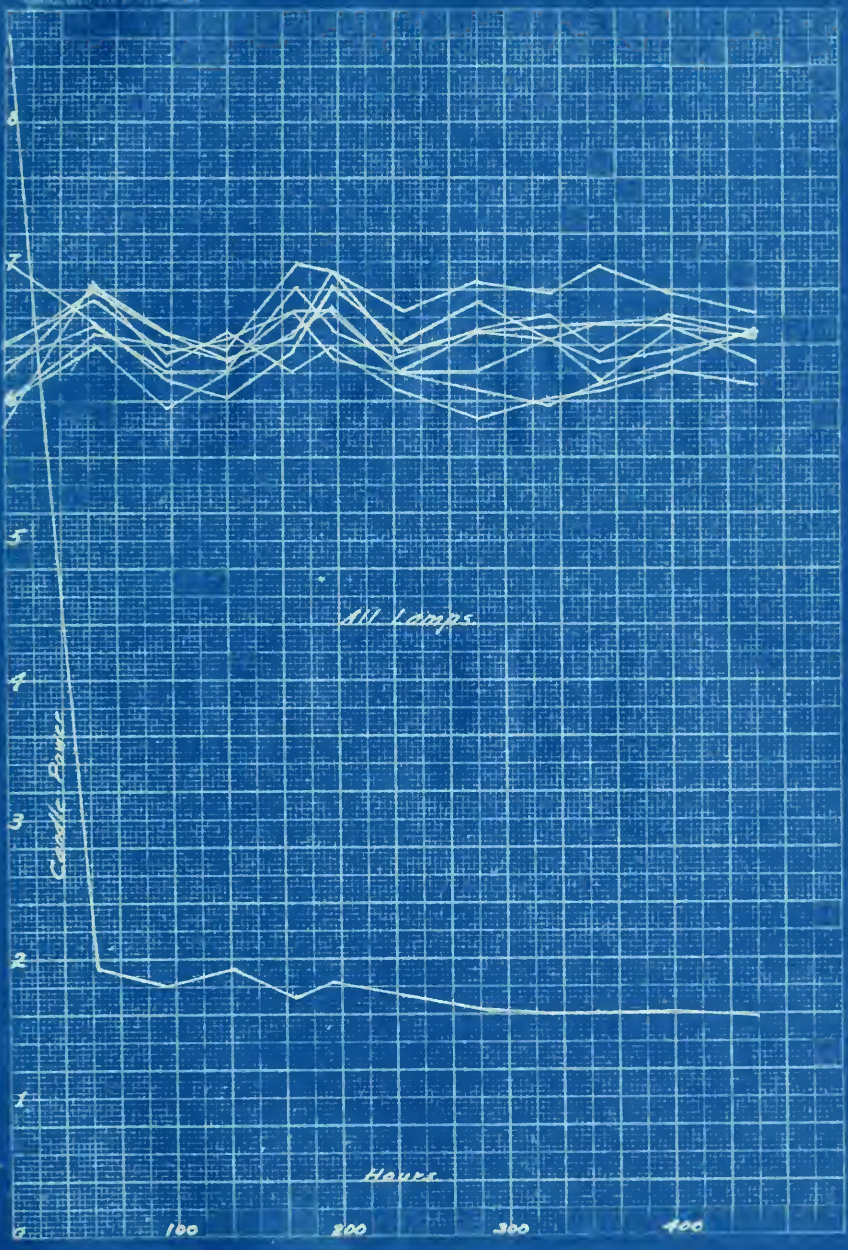

Lamp. G
Candle Power
6
5
4
3
2
1
Hours.
0
100
200
300
400

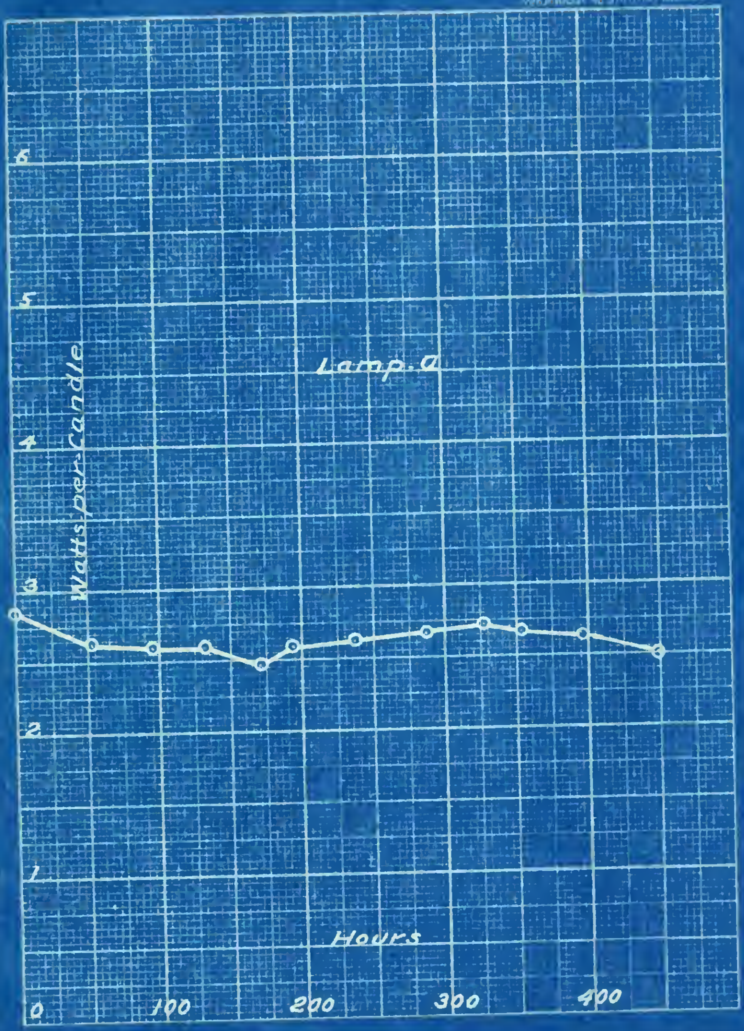


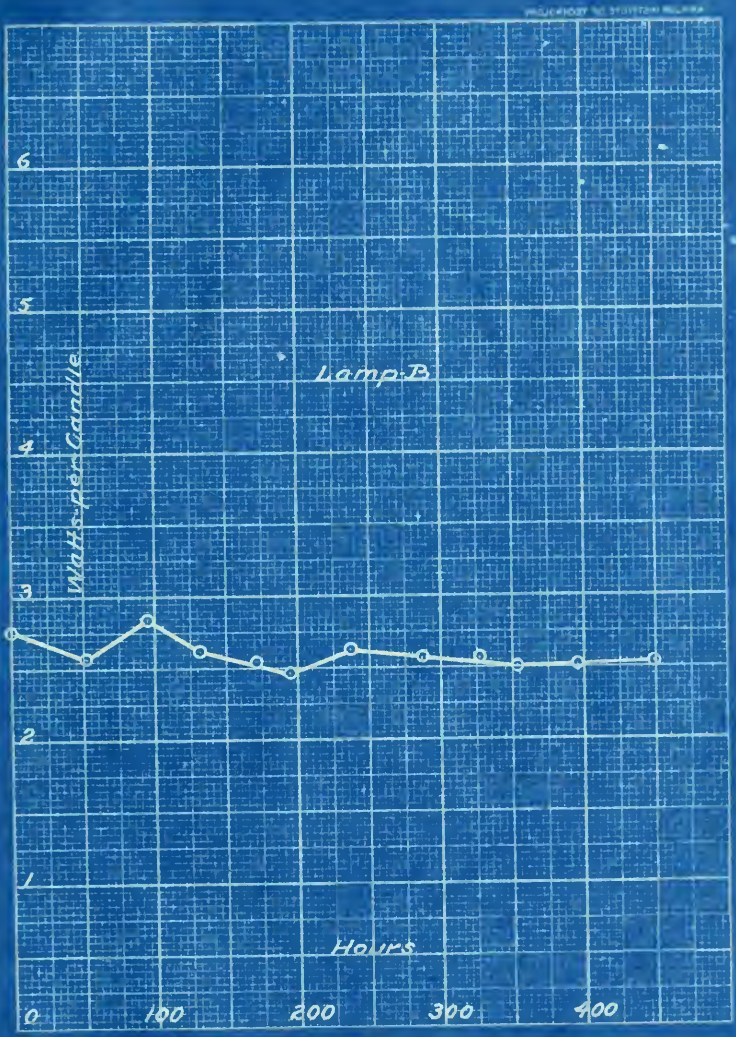
Lamp H
Candle-Power
Hours
6
5
4
3
2
1
0
100
200
300
400


Lamp-I
Candle-Power
6
5
4
3
2
1
0
100
200
300
400
Hours


Lamp J
Candle-Power
6
5
4
3
2
1
0
100
200
300
400
Hours


6
7
All Lamps
5
4
Candle Power
3
2
1
Hours
0
100
200
300
400


Lamp. a
Watts per candle
6
5
4
3
2
1
0
100
200
300
400
Hours


Lamp B
Watts per Candle
Hours
6
5
4
3
2
1
0
100
200
300
400

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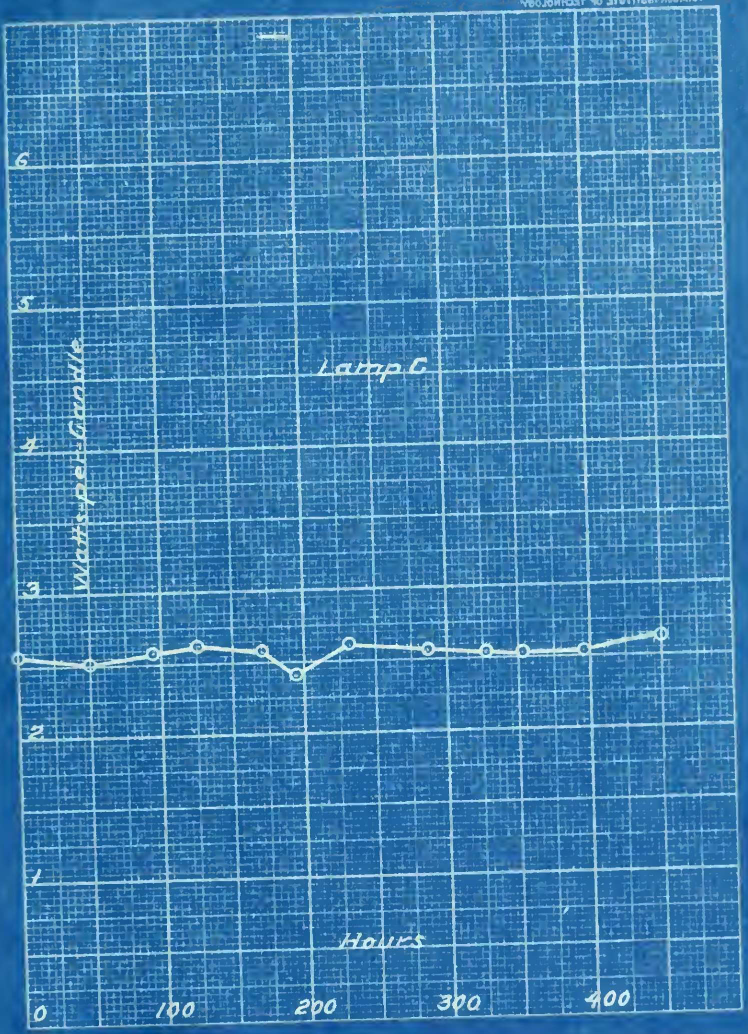
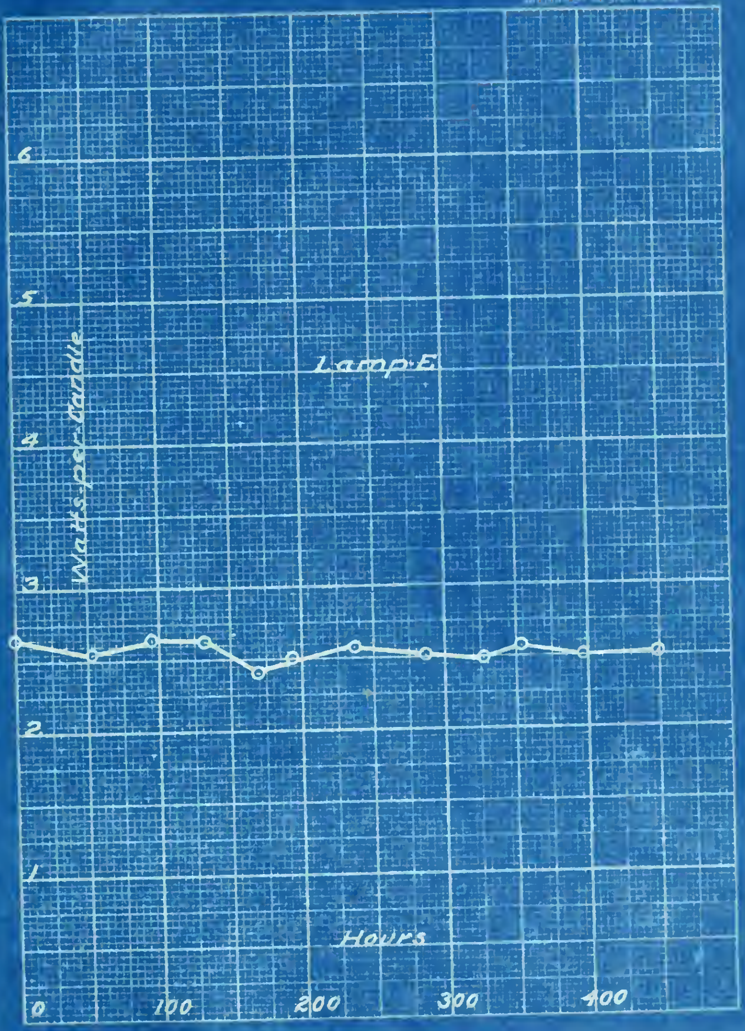
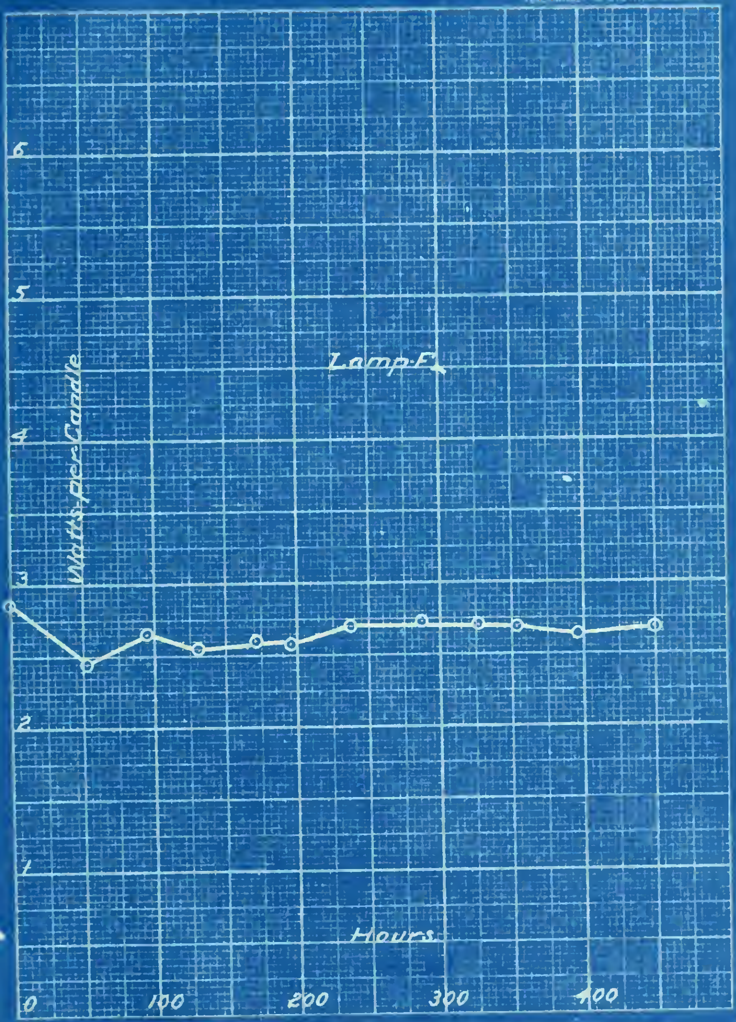
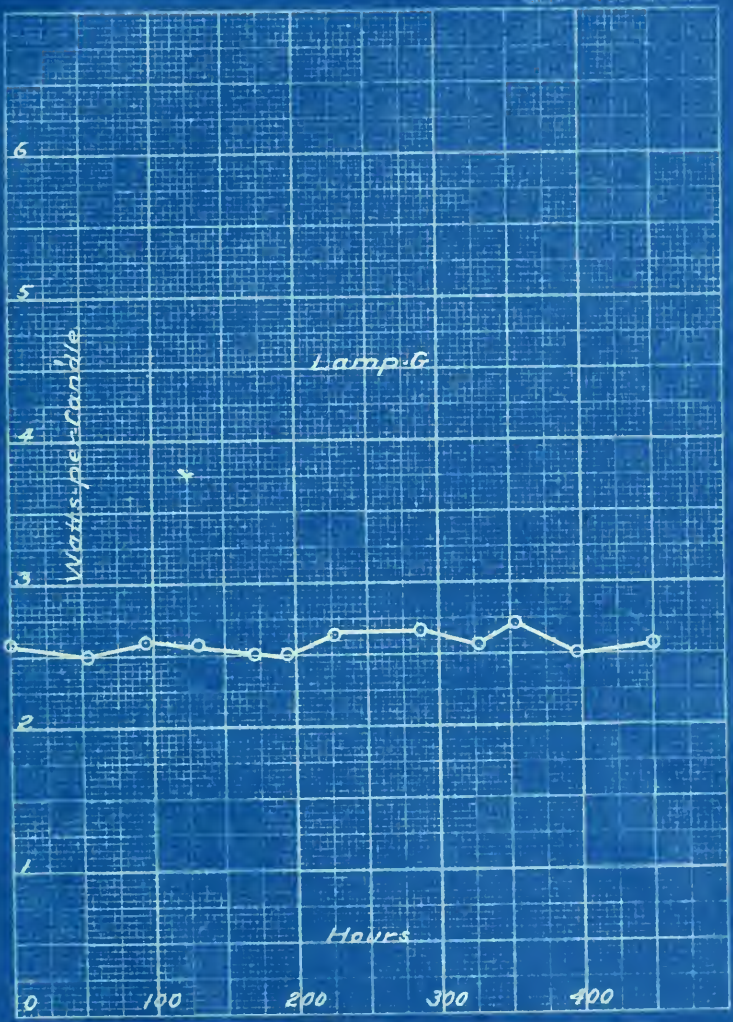
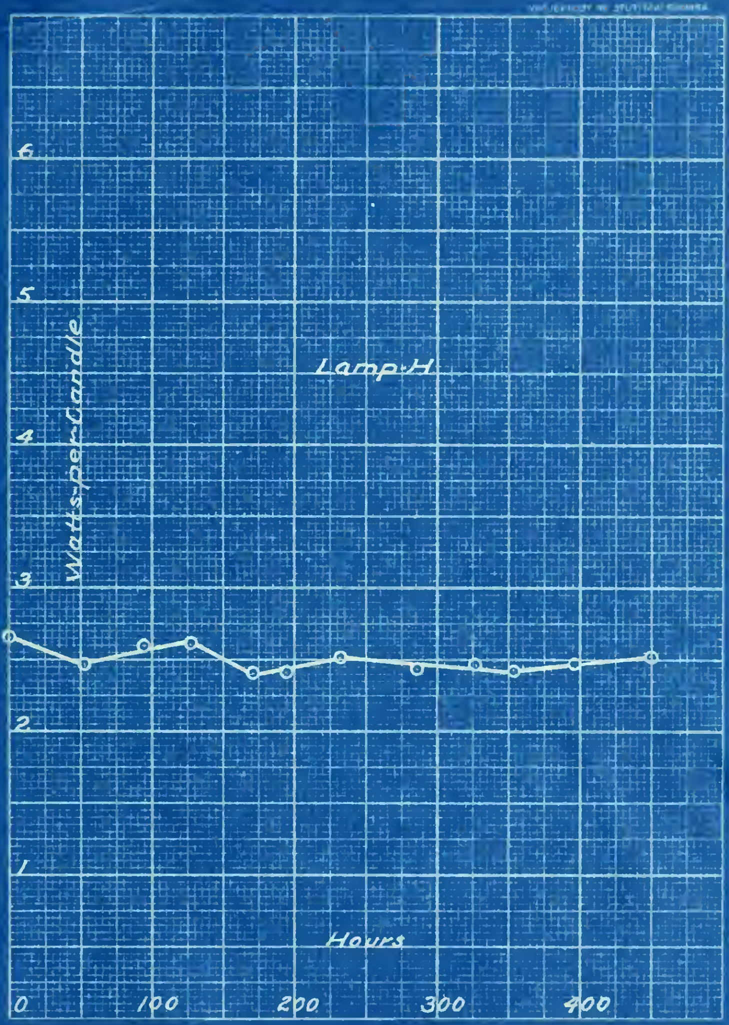
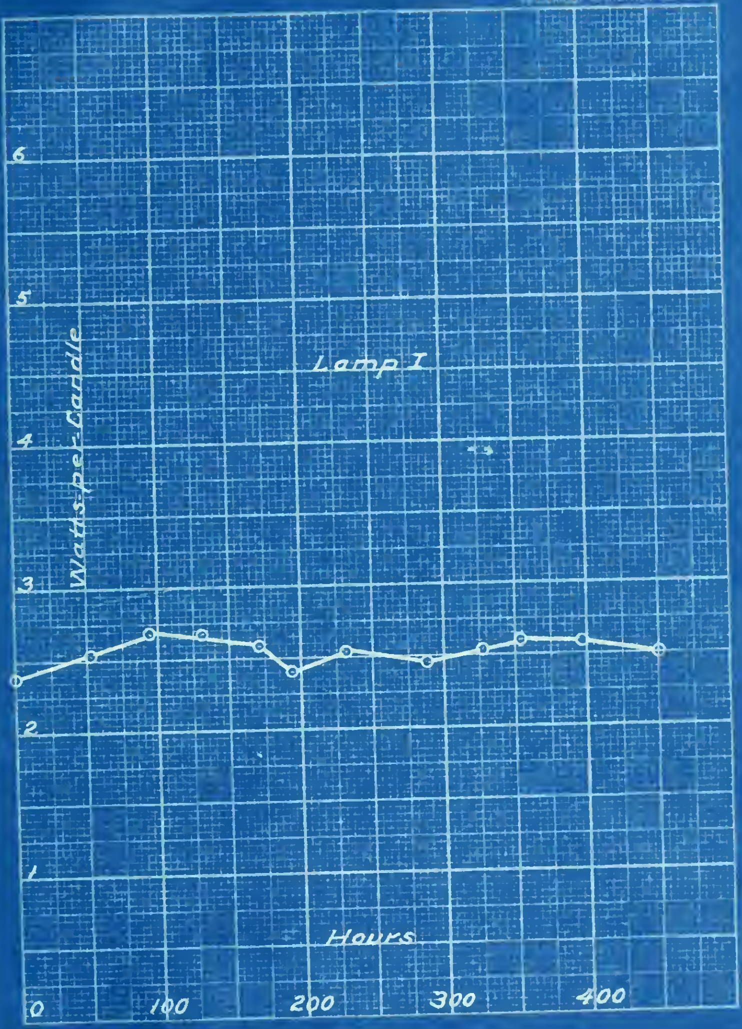


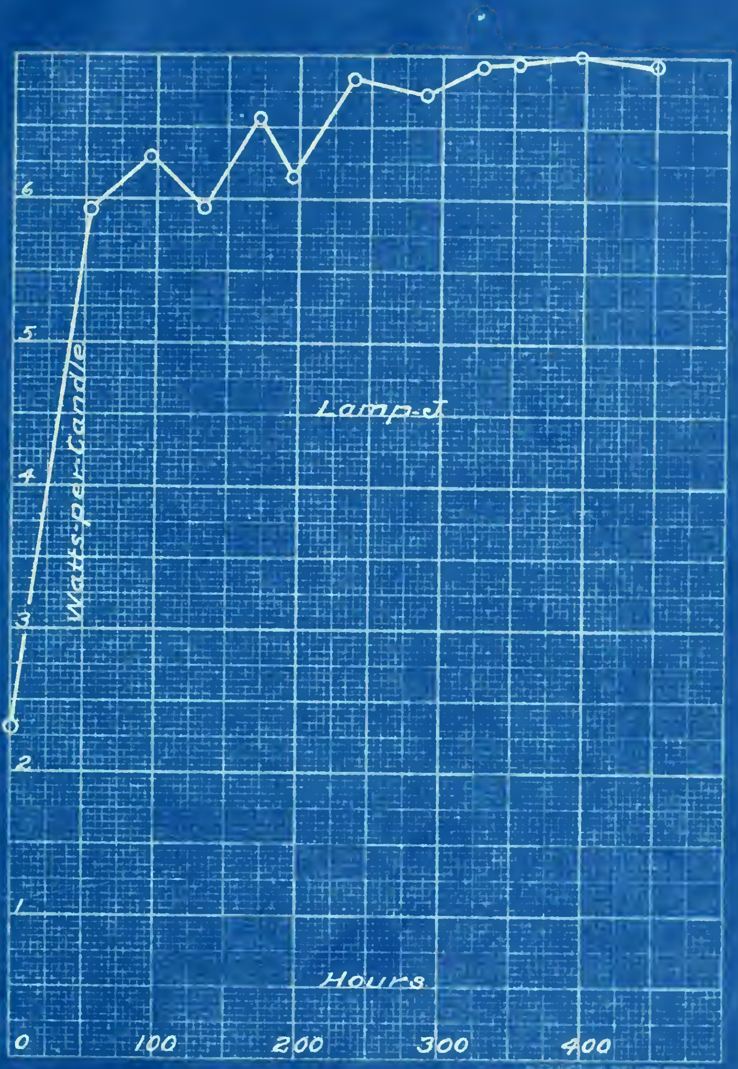

Lamp E
Watts per Candle
6
5
4
3
2
1
0
100
200
300
400
Hours


Lamp F.
Watts per Candle
6
5
4
3
2
1
0
100
200
300
400
Hours.


Lamp G
Watts per candle
Hours
6
5
4
3
2
1
0
100
200
300
400


Lamp H
Watts-per-Candle
6
5
4
3
2
1
0
100
200
300
400
Hours


Lamp I
Watts-per-Candle
6
5
4
3
2
1
Hours
0
100
200
300
400


Lamp-J
Watts-per-Candle
Hours
6
5
4
3
2
1
0
100
200
300
400

CONCLUSION

From the preceding curves it can easily be seen that the series tungsten lamp cannot be used as a standard until it has been "seasoned", that is, burned for at least one hundred and fifty hours. After that period the candle-power becomes much steadier, but of all the lamps under test, with the possible exception of B, C and J, this variation is greater than three per cent, which is about all we can safely charge to errors of observation. Lamp J cannot be considered, as it was burning at a much higher specific consumption than the others, due to some imperfection in the lamp. This leaves only B and C which come up to the requirements.

The natural conclusion is that these lamps will not serve as reliable secondary standards, but it is very probable that the lamps did not become thoroughly "seasoned" in the time that we burned them, and if the test had been extended for an extra five hundred or thousand hours the results might have been such that would warrant the series tungsten lamp to be used as a secondary standard for photometric work.